Approved for public release;
distribution unlimited.

AD

AD-724 648

TECHNICAL REPORT

71 - 40 - CE

THE BEHAVIOR OF PROTECTIVE UNIFORMS IN LARGE SCALE SIMULATED FIRES

By

Textile Research and Engineering Division

Project Reference:
1T062105A329

Series: TS-172

March 1971

Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Natick Laboratories Natick, Mass. 01760	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

The Behavior of Protective Uniforms in Large-Scale Simulated Fires

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Textile Research and Engineering Division

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1971	44	4

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 1002440lA329	71-40-CE (TS-172)
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Natick Laboratories Natick, Massachusetts 01760

13. ABSTRACT

This report describes a new test facility developed at the U. S. Army Natick Laboratories for exposing clothed manikins to large fuel (JP-4) fires and gives the results of evaluations made of several protective systems developed for hot and cold weather aviators' uniforms. Measurement of temperature attained on the manikin surface (Temperature-Area Index) and visual examination of the burning and the burned items, revealed significant advantages in using thicker systems when permitted by environmental conditions of wear. In terms of Average Temperature-Area Index and After-Appearance Evaluation of Hot-weather uniforms, polybenzimidazole fiber performed better than the other heat resistant fiber types available when these tests were run. Because of the small sample size, it was difficult to demonstrate that the differences observed were significant statistically. Sources of variability in the test procedure are discussed and suggestions are made for dealing with the considerable variability associated with large scale fires of this type.

FOREWORD

The changing nature of warfare requires constant attention to the development of protective systems to defeat new hazards introduced by weaponry or equipment. The widespread use of helicopters in Vietnam has introduced the hazard of potentially survivable post-crash fires which claim more lives than crash injuries. Work is in progress to reduce fuel spillage and to delay ignition in helicopter crashes, but reliance at present must be placed on the uniform system to provide required levels of protection.

The availability of a variety of non-melting, heat resistant fibers has stimulated the development of protective garments which will resist ignition and minimize heat transfer for the seconds required for aircraft personnel to escape from the fire-ball. In view of the limitations of laboratory instruments for assessing the suitability of clothing systems for flame protection, a full-scale facility was designed and developed for evaluating items under simulated field conditions. This report presents some information on the design of this facility, the development of several protective aviators' uniform systems, and the results obtained in evaluating the uniforms in the test facility. This report should be considered a preliminary statement of the effectiveness of the cold-weather and hot-weather items which were evaluated. Based on the findings, additional studies are planned to provide more definitive answers to the levels of protection which can be achieved.

The work described is based on studies conducted under the supervision of Mr Earl T. Waldron. Contributing to obtaining the basic data and in the analysis of the results were Mr. Walter M. Koza, Mr. Robert J. Goff, Mr. William F. Smith, and Mr. Michael E. Mahar. The work was done under the program management of Mr. Allan J. McQuade and Mr. Frank J. Rizzo. The contributions of Capt. Robert M. Stanton, Mr. Jack H. Ross and Mr. Stanley Schulman of the Air Force (AFML, AFSC) and Miss Alice M. Stoll of the Navy are gratefully acknowledged. Appreciation is expressed to Mr. Louis I. Weiner for his assistance in compiling this report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This report describes a new test facility developed at the U S Army Natick Laboratories for exposing clothed manikins to large fuel (JP-4) fires and gives the results of evaluations made of several protective systems developed for hot and cold weather aviators' uniforms. Measurement of temperature attained on the manikin surface (Temperature-Area Index) and visual examination of the burning and the burned items, revealed significant advantages in using thicker systems when permitted by environmental conditions of wear. In terms of Average Temperature-Area Index and After-Appearance Evaluation of hot-weather uniforms, polybenzimidazole fiber performed better than the other heat resistant fiber types available when these tests were run. Because of the small sample size, it was difficult to demonstrate that the differences observed were significant statistically. Sources of variability in the test procedure are discussed and suggestions are made for dealing with the considerable variability associated with large-scale fires of this type.

1. INTRODUCTION

Experience in Vietnam has emphasized the need for a clothing system which will increase the level of protection and therefore the probability of survival of aviators in potentially survivable post-crash fires. The greatest number of casualties in Army aircraft accidents involve post-crash fires, and survival in fire accidents is most difficult in rotary-wing aircraft. Considerable research is in progress to design aircraft with more inherent resistance to fuel spillage and ignition. Until such aircraft are developed reliance must be placed on uniforms which will provide the highest possible degree of protection.

Preventing or minimizing burns is just one element in the complex of factors which determine a man's ability to survive a post-crash fire. Crash induced injuries, toxic fumes, visibility, and psychological factors influence ability to egress from the vehicle and pass through the fire-ball within the time period necessary to prevent serious burn damage. In studies of post-crash fires, three areas of investigation are normally considered: the cockpit environment, the fireball which must be traversed, and the respiratory hazard.

In connection with the cockpit environment, Turnbow[1] plotted relationships between circumambient temperature and temperature of the radiant source against pain threshold time, which provides an indication of the time available for escape from a fire under specific ambient conditions of temperature and energy. While it is not possible from studies of this type to predict the exact number of seconds of protection that a uniform system must provide to significantly increase survival rate, it must be assumed that any level of increased protection without impairing other functional characteristics of the clothing will be desirable. USAF aircrew survival experience suggests that three (3) seconds of complete exposure in a JP-4 fire is the maximum survivable with any operationally acceptable fabric.

This report covers three aspects of work undertaken at the U. S. Army Natick Laboratories with the objective of developing a practical combat uniform system to increase protection against post-crash aircraft fires. The first step was the development and construction of a full-scale fire-test facility which simulates the conditions for exiting of personnel through flame during a rotary-wing aircraft post-crash fire. This facility was modeled after a prototype used originally at the U.S. Army Chemical Center. The second step was the design and development of model uniforms, including

the utilizatior of appropriate material components and fiber types which would provide the range and level of protection required. And, the third step was the evaluation of the uniforms in the fire-test facility. Both cold-weather and hot-weather uniform systems were evaluated. A group of hot-weather coveralls made from a variety of heat-resistant fibers was evaluated at the request of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. These studies represent a cooperative effort by various Department of Defense agencies together with industrial organizations. The contributions made by personnel of the U. S. Army Aeromedical Laboratory, Fort Rucker, Alabama in their review of the data is noted.

2. DESIGN OF THE FIRE-PIT FACILITY

The facility consists of a shallow pit, 30 ft. long by 20 ft. wide, lined with an impermeable barrier, back-filled with 3 inches of fine sand, and partitioned with 4-inch steel T-beams. At one end of the pit there is a concrete wall fitted with fire doors which can be opened at the appropriate time to permit the entrance of the manikins. The other three sides of the pit are open. The manikins (Figure 1) are mounted on a 3/4-inch steel rope which can be set in motion traversing the long dimension of the pit at velocities of 3, 5, or 10 feet per second. The steel rope is approximately 10 feet above the level of the pit when filled. The feet of the manikins reach to within about 12 inches of the pit. The T beams are positioned in the pit so that a wide range of exposure times of the manikins to the flame may be obtained. The relationship of exposure time to the distance between the T beams for typical traversal velocities is shown in Table I.

Initially, the pit is loaded with water to within one inch of the top of the inverted steel T beam partitions, thus forming a water seal between sections. JP-4 fuel is distributed in the required number of sections to provide a coverage of 0.04 gallons per square foot; fuel is ignited and one, two, or three clothed manikins are drawn through the fire.

In view of the considerable variability in the nature of the actual fire, various techniques have been used to obtain some measure of the reproducibility within and between tests. A thermocouple rake consisting of platinum and platinum-rhodium thermocouples mounted 1 foot apart in a vertical plane 6 feet distant from the fire-wall was installed to provide a history of the temperature profile in that plane. A radiation-calorimeter[2] is positioned approximately 18 feet from the end of the pit opposite the fire-wall to monitor the increase in intensity of the fire.

TABLE I

FIRE-PIT TEST EXPOSURE TIMES

Distance Between T Beams (Ft) \ Velocity of Rope (Ft/Sec)	3	5	10
12	4.0*	2.4	1.2
18	6.0	3.6	1.8
24	8.0	4.8	2.4
30	10.0	6.0	3.0

* Values in Body of Table are Exposure Times in Seconds

A fire truck sourced stream of high pressure water can be utilized to create a water barrier between the flames in the fire-pit and the manikins after the manikin exits from the fire. This reduces the radiant heat load so that operating personnel can remove the manikin from the steel rope to an area where visual and photographic analysis can be made. In addition, this reduces the continuing absorption of radiation from the flame by the uniforms. Cameras are positioned at the back and one side of the fire-pit to provide a pictorial history of each manikin's traverse through the fire.

FIGURE 1 - Manikins Exiting from Fire-Pit Facility

3. DESCRIPTION OF THE MANIKIN

The manikins used in the flame-pit tests to-date have been commercially available models fitted with ring supports at the shoulders to facilitate mounting. The manikins are painted with white epoxy paint to allow for their re-use. The dimensions of the manikin, as shown in Table II, approximate those of a size 38 man. The arms of the manikin articulate at the shoulders but the legs do not. The shell of the manikin, made by embedding fibrous glass tow in polyester resin, was flame resistant and relatively stable to heat. The thickness of the shell ranges from .09 inches to .40 inches (in reinforced areas). The density of the shell is 1.48 gm/cm^3, the specific heat .34 Btu/lb^{o}F, and the thermal conductivity 3.7 x 10^{-4} cal/cm^2sec^{o}C cm. In this connection, it has been noted by Chen(3) that under similar time-temperature patterns, materials will accept heat at the same rate if the products of thermal conductivity, heat capacity and density (KPC product) are equal. It is interesting that the KPC product for the manikin shell is closer to that of human skin than a proteinaceous material like leather. The KPC product for the manikin shell is less than that of human skin by a factor of 4.7 whereas leather would be less than that of human skin by a factor of 17.3. Figure 2 pictorializes front and back views of an assembled manikin with the locations of the temperature indicating papers shown.

4. TEMPERATURE INDICATING PAPERS

The temperature indicating papers developed by Loconti(4) are used to measure the maximum temperature reached in the various locations of the manikin surface. These papers consist of temperature sensitive organic pigments printed on black absorbing paper. Each pigment is printed to read the temperature of its melting point. As this temperature is reached, the pigment melts and is absorbed by the paper. The effect produced is a change from a light-colored pigment on a black background to a completely black background. Thus, a permanent record is provided of the temperature by the pigments which have melted. In general, the changes from white to black occur very sharply, usually within a 1 to 2^{o}C temperature range. A sequence of five temperature indicating papers is used with melting points of 169, 200, 221, 240, and 260^{o}F. As shown in Figure 2, these are positioned on each manikin in the following manner: right and left anterior and posterior trunk; right and left buttocks, genitalia; both arms, upper and lower; both thighs and lower legs, front and rear.

TABLE II

PHYSICAL CHARACTERISTICS OF THE MANIKIN

COMPOSITION	Fibrous Glass Tow Embedded in Polyester Resin
WEIGHT	
Torso	6.34 lbs
Lower Body	9.53 lbs
	15.87 lbs
DIMENSIONS (Size 38)	
Torso	Chest - 38" Waist - 32.5" Biceps - 13" Arm Length - 25.5"
Lower Body	Leg Length (to Crotch) - 32" Calf - 15"
THICKNESS	.09" to .40" (at Reinforcements)
THERMAL CONDUCTIVITY	3.7×10^{-4} Cal/cm^2 sec ^{o}C cm
DENSITY	1.48 gm/cm^3
SPECIFIC HEAT	.34 Btu/lb ^{o}F
KPC*	1.8×10^{-4}

* Thermal Conductivity x Density x Specific Heat

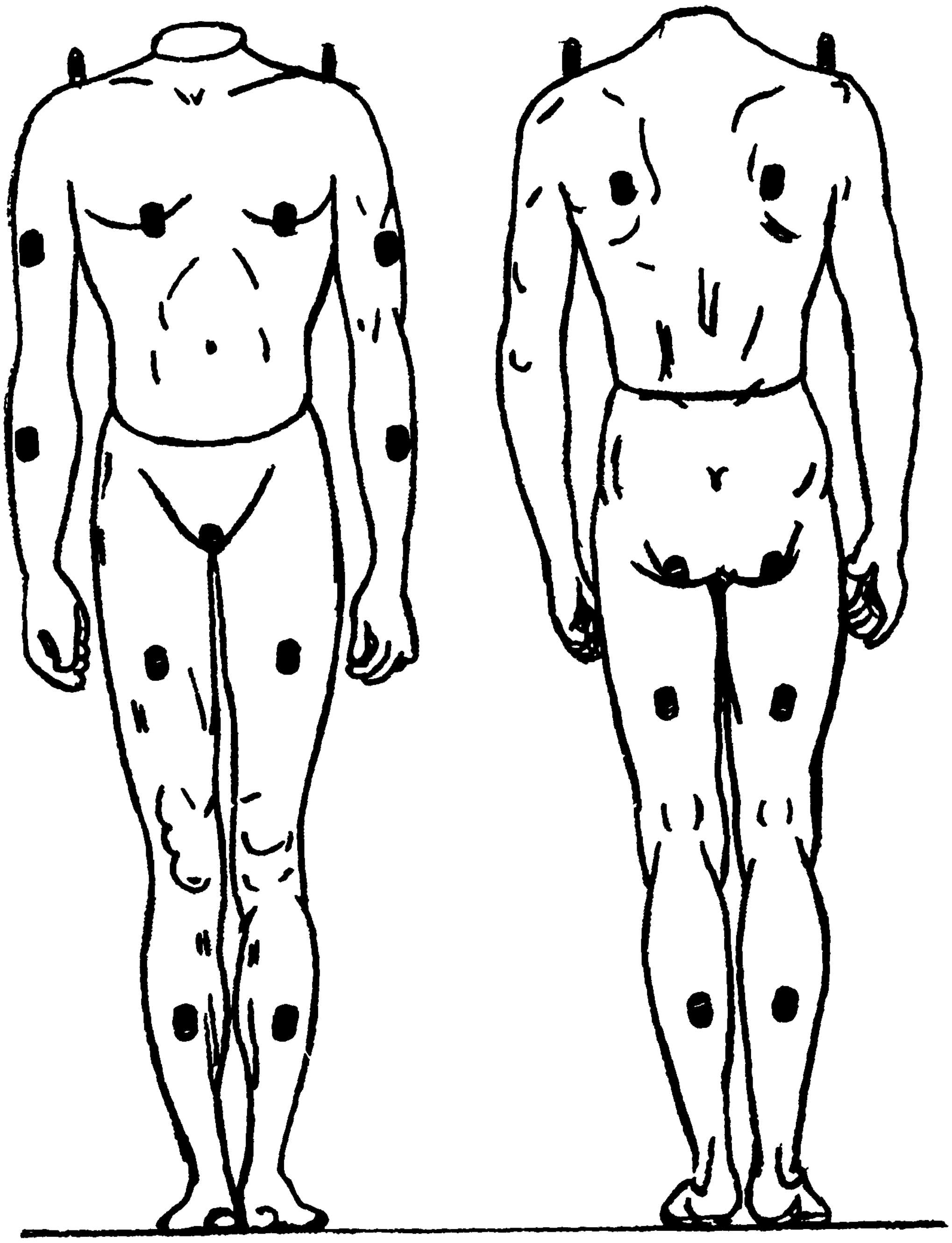


Figure 2 - Front and Rear Views of Manikin Showing Location of Temperature Indicating Papers

5. UNIFORM SYSTEMS

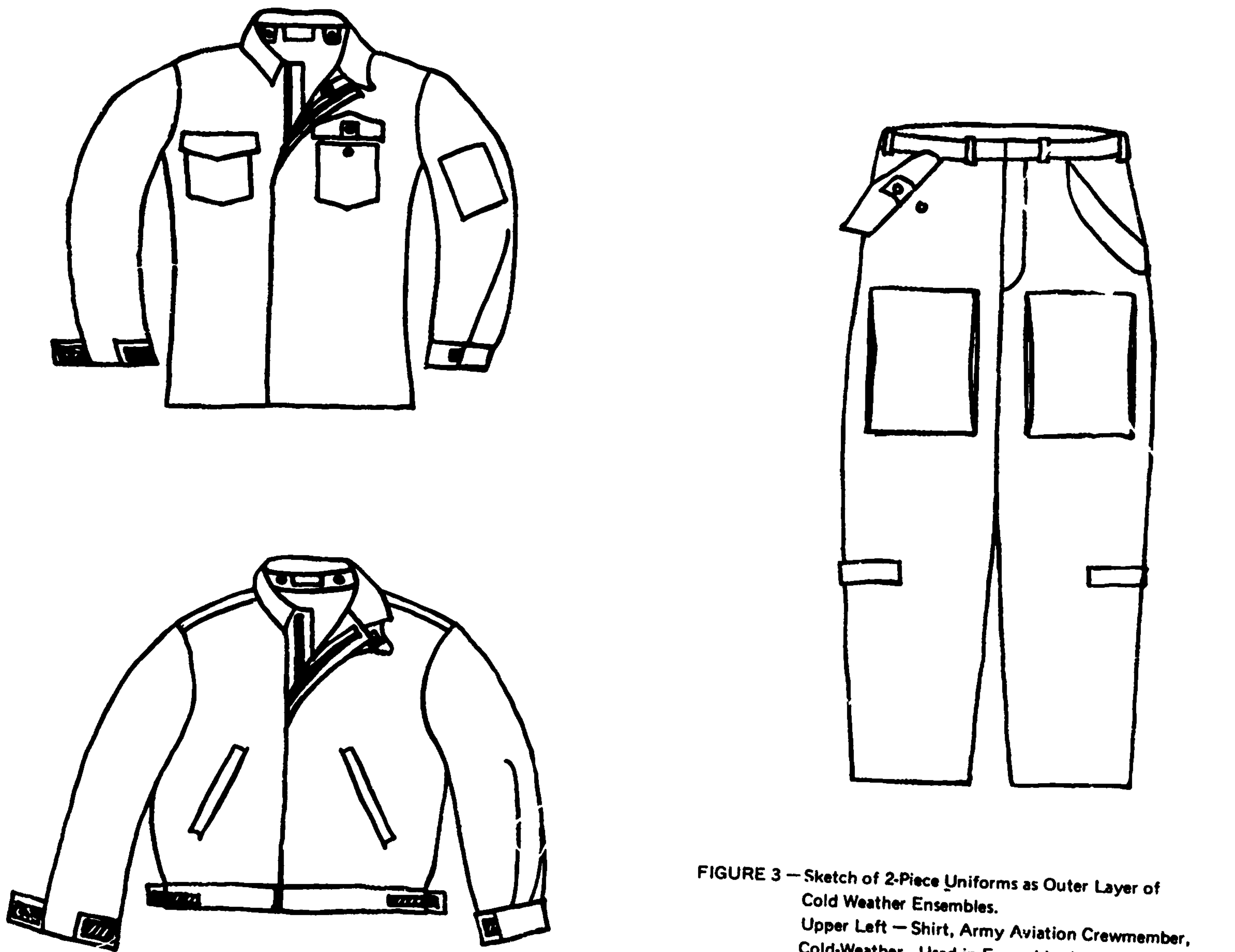
The outer garments used for the tests were of two types: (1) a conventional two-piece uniform with shirt or coat and trousers as the outer layer; and (2) a one-piece coverall as the outer layer. The cold-weather garments were backed by a minimum of three additional layers of clothing. The hot-weather garments were backed only by tee shirts and shorts. The fibers used in all of the outer garments were of the heat resistant, non-melting type. In the cold weather ensembles one or more of the underlayers were also made from these non-melting fiber types.

The performance expected from the protective ensemble is considered to be a function of the fiber type, garment design and coverage, and the spacing between layers. The major function of the heat-resistant fiber in the outer layer, over and above its insulating effect, is to maintain its physical integrity to the greatest extent possible, to act as a barrier between the flame and the inner-layers of the system. The air layer or layers behind the outer-garment reduce convective and conductive heat transfer, hopefully to the point that temperatures and energy transfer are reduced to tolerable levels. The garment design provides the necessary areal coverage. Closures and the capacious pockets provide additional layers for reducing convective and conductive heat transfer. More detailed description of the cold-weather and hot-weather uniforms are given in the following paragraphs, and specific performance characteristics of the material components are contained in the Appendices.

a. Cold Weather Uniforms

The cold-weather uniform assemblies varied appreciably in terms of design, components, fabric and fiber types but all used non-melting fibers in the outer layer. All of the outer garments were two piece, consisting of jacket and trousers. Five of the six uniforms were of the type illustrated at the upper left and right of Figure 3, which corresponds to Purchase Descriptions DES 10-69 and DES 15-69. These are one layer uniforms made from 4.4 oz/yd^2 commercial aromatic polyamide twill. The sixth uniform (Type 4) used a different jacket design (DES 9-69) as illustrated at the lower left of Figure 3. This "Eisenhower" type jacket is also made from one layer of 4.4 oz/yd^2 commercial aromatic polyamide twill.

Each ensemble consisted of the outer garment, an insulating layer, an inner shirt and trousers, and underwear. The inner-trouser layer of the Type 4 ensemble also served as the outer-trouser layer of the outer garment. The insulating layers



(Fabric — 4.4 oz/yd^2 Commercial Aromatic Polyamide)

FIGURE 3 — Sketch of 2-Piece Uniforms as Outer Layer of Cold Weather Ensembles.
Upper Left — Shirt, Army Aviation Crewmember, Cold-Weather, Used in Ensembles I, II, III, V, and VI.
Lower Left — Jacket, Army Aviation Crewmember, Intermediate (Eisenhower Type) Used in Ensemble IV.
Right — Trousers, Army Aviation Crewmember, Cold Weather Used in All Cold-Weather Ensembles

were either quilted commercial aromatic polyamide or polyester battings or frieze; the inner shirt and trouser layers were either commercial aromatic polyamide or wool*; and the underwear layers were either wool/cotton or cotton/commercial aromatic polyamide blends. The exact arrangements of the various fabric components are shown in Figure 4. The total number of fabric layers for a given ensemble varied from five to seven. The alphanumeric designations in the second column of Figure 4 indicate the number of fabric layers of each type of fiber in the uniform system. Thus, for the Type 1 ensemble, $Ca^{1}Ny^{2}Po^{1}W^{1.5}C^{.5}$ denotes one layer each of commercial aromatic polyamide and polyester, two of nylon, 1.5 of wool, and 0.5 of cotton, for a total of 6 layers. The ".5" value arises from the fact that the underwear layer was 50% cotton/50% wool. The thickness and areal densities of the component layers of the cold-weather uniforms are shown in Table III. Additional details on the physical characteristics of the various fabrics composing the cold-weather uniforms are contained in the Appendix.

b. Hot-Weather Uniforms

The hot-weather uniforms were of three different designs, two Army and one Air Force. The Army designs were a one-piece, two-layer coverall, commonly called the "Army Tankers' Coverall", illustrated on the left of Figure 5 and a two-piece, one-layer uniform commonly called the "Army Two-Piece Uniform", illustrated on the center and right of Figure 5. The fabric layers in both of these uniforms is a 4.4-ounce commercial aromatic polyamide twill. The Air Force uniforms were one-piece, one-layer coveralls illustrated in Figure 6. The Air Force uniforms were used as a vehicle for evaluating a variety of fabric and fiber types. The latter was an experimental blended fabric that was tried to see the effect of blending PBI with an aromatic polyamide. A description of the fabrics is given in Table IIIA.

* The wool shirt contains 15% nylon.

LAYER ARRANGEMENT IN COLD-WEATHER ENSEMBLES

TYPE	NUMBER OF FABRIC LAYERS	First	Second	Third	Fourth	Fifth	Sixth	Seventh
I	$Ca^{1}Ny^{2}Po^{1}W^{1.5}C^{.5}$	Ca	Ny	Po	Ny[1]	W[2]	W-C[3]	
II	$Ca^{4}W^{1.5}C^{.5}$	Ca	Ca	Ca	Ca	W	W-C	
III	$Ca^{3.5}Ny^{2}Po^{1}C^{.5}$	Ca	Ny	Po	Ny	Ca	Ca	C-Ca
IV	$Ca^{6.5}C^{.5}$	Ca[4]	Ca	Ca	Ca[5]	Ca	Ca	C-Ca
V	$Ca^{2}W^{2.5}C^{.5}$	Ca	W	Ca	W	W-C		
VI	$Ca^{3}Po^{1}W^{1.5}C^{.5}$	Ca	Ca	Po[6]	Ca	W	W-C	

1 ——— = Liner
2 The Wool Layer for the Upper Torso Contained 15% Nylon
3 W-C = Blend Wool + Cotton
4 Jacket Only
5 Liner Only for Jacket
6 Fire-Resistant Polyester

LEGEND

Ca = Commercial Aromatic Polyamide
Ny = Nylon
Po = Polyester
W = Wool
C = Cotton
Superscript indicates number of layers

Figure 4 — Arrangement of Fabric Layers from Outside (Left) to Inside (Right) of Uniforms

TABLE III

THICKNESS AND WEIGHT OF THE VARIOUS LAYERS OF THL COLD-WEATHER UNIFORM SYSTEMS

FABRICS	THICKNESS (.05 psi)(Inches)	WEIGHT (Oz/Yd^2)
Commercial Aromatic Polyamide (Ca)*	.02	4.4
Wool 85%/Nylon 15% Shirting	.10	11.1
Wool Serge	.05	11.4
BATTINGS/LINING		
Polyester/Nylon	.37	6.2
Ca/Ca*	.31	11.0
FR** Polyester/Ca	.38	10.4
Frieze/Ca	.32	19.2
UNDERWEAR		
Wool/Cotton	.068	8.9
Cotton/Ca	.051	5.8

* Ca = Commercial Aromatic Polyamide
** FR = Fire-Resistant

TABLE IIIA

DESCRIPTION OF FABRICS USED IN HOT-WEATHER UNIFORMS

NOMENCLATURE	WEIGHT (oz/yd^2)	WEAVE	COLOR
PBI (polybenzimidazole)	4.8	2/1 Rt	Gold
Modified Aromatic Polyamide	4.5	1/1 Plain	Gold
Aromatic Polyamide A	4.7	2/2 Left	Green
Aromatic Polyamide B	4.3	2/2 Left	Green
Aromatic Polyamide C	4.6	2/2 Left	Green
PBI/Ca*	4.8	2/1 Left	
Ca * (For Army 2-piece)	4.4	2/2 Left	OG
Ca* (For Army Tankers)	4.4	2/2 Left	OG

* Ca = Commercial Aromatic Polyamide

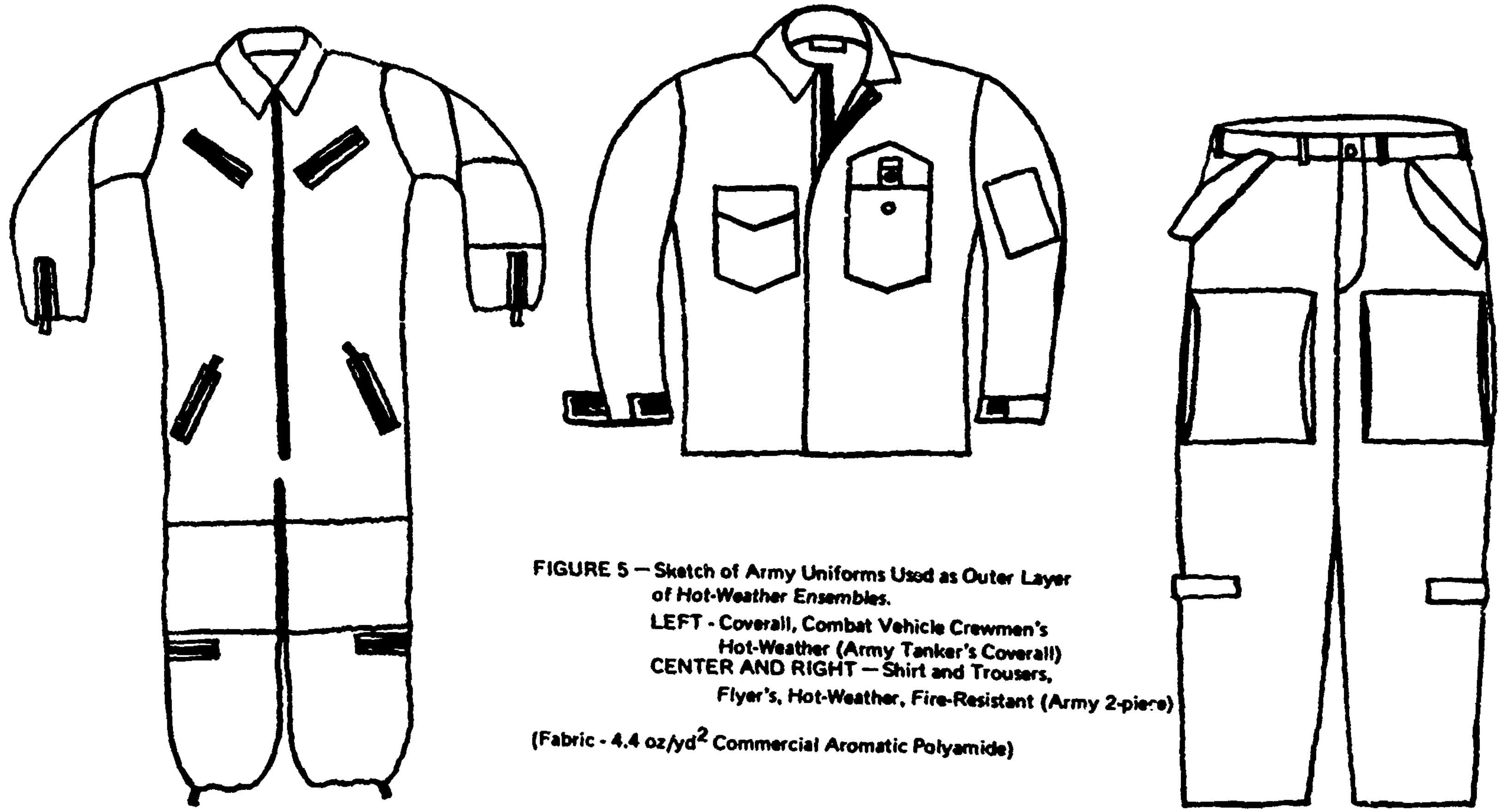


FIGURE 5 — Sketch of Army Uniforms Used as Outer Layer of Hot-Weather Ensembles.
LEFT - Coverall, Combat Vehicle Crewmen's Hot-Weather (Army Tanker's Coverall)
CENTER AND RIGHT — Shirt and Trousers, Flyer's, Hot-Weather, Fire-Resistant (Army 2-piece)

(Fabric - 4.4 oz/yd^2 Commercial Aromatic Polyamide)

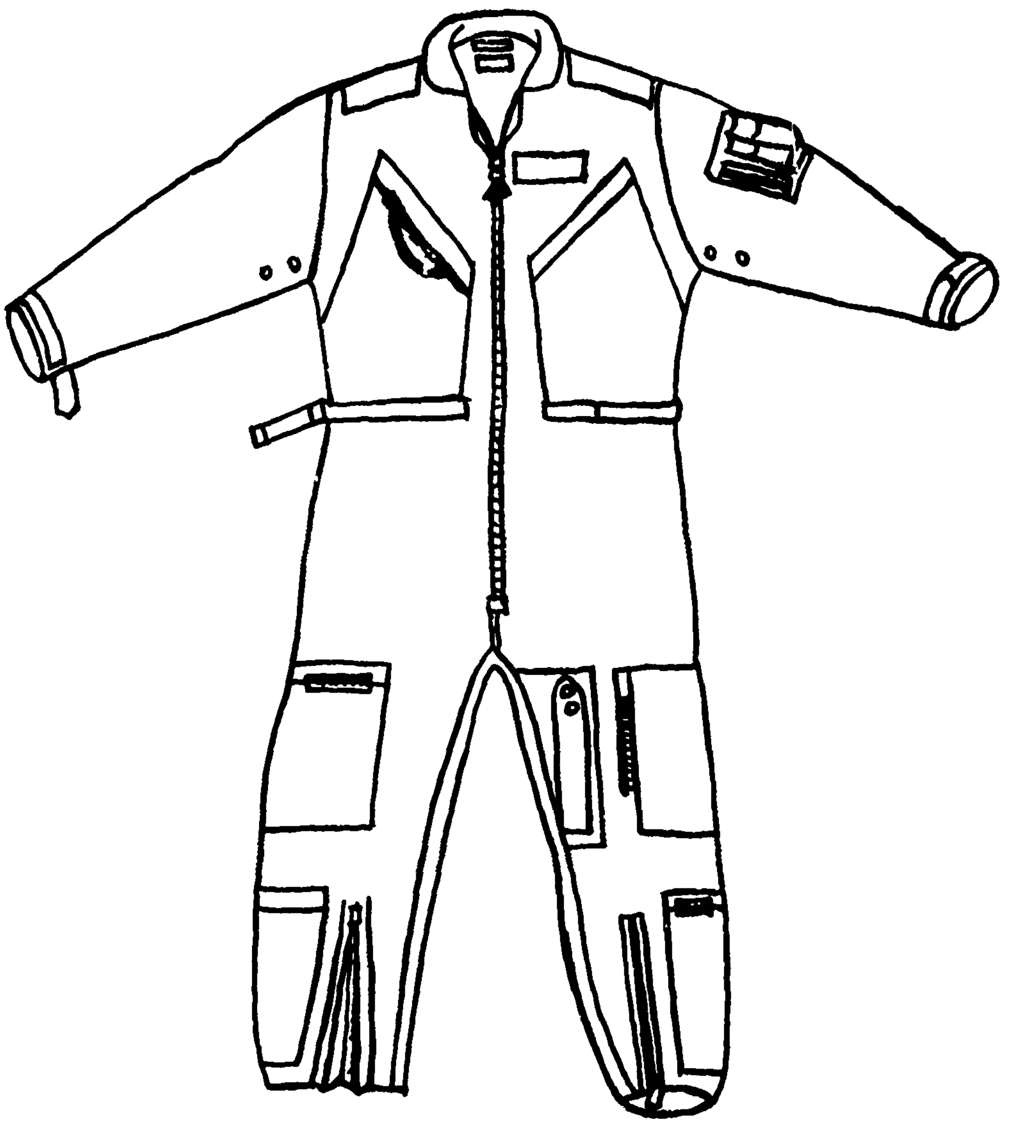


FIGURE 6 — Sketch of Air Force One-Piece Coverall
Used as Outer Layer of Hot-Weather Ensembles
Made According to Specification for Coveralls,
Flying, Men's Summer, Fire-Resistant
(Fabrics - PBI (Polybenzimidazole), PBI/Commercial
Aromatic Polyamide Blend, Commercial Aromatic
Polyamide, and Modified Aromatic Polyamide)

6. EVALUATION PROCEDURES

Evaluation of the results of the tests was made by the use of three parameters:

a. Temperature-Area Index - defined in next section - "Sources of Variability."

b. Post-Exposure Flaming (for the winter-weight uniforms)

c. Garment damage (for the summer-weight uniforms)

a. Temperature-Area Index

An ultimate objective in the use of the Temperature-Area Index parameter would be to be able to relate it to burns. The state-of-the-art does not permit such correlation at the present time. For the purpose of this study, the Temperature-Area Index is based only upon an observed temperature at the manikin surface and the area of the manikin which could be associated with that temperature.

b. Post-Exposure Flaming

In relatively high-mass systems, such as the cold-weather uniforms, sufficient organic matter is available in the form of unburned fiber in the outer and inner layers of the garment to continue flaming even after the uniform has exited from the fire-pit. (An indication that the ignition threshold temperature has been exceeded.) Since the post-exposure flaming can be a hazard in itself, a technique was devised to quantify this parameter. The data were extracted from color motion pictures taken over a short interval of 5 seconds beginning at the exact moment the manikin left the fire. An estimated post-exposure flaming score was computed by assuming three flame levels (1,2, and 3) and integrating these levels over the length of the manikin (total length = unity). In instances where flaming was found to be equivalent on both the front and the back of the manikin, the appropriate components of the index were doubled before summing. The sketch in Figure 7 illustrates the method of computing the post-exposure flaming score.

c. Garment Damage

Since flame contact data were obtained in the laboratory which had good relation to the actual garment exposures, no post-exposure flaming was evaluated for the hot-weather uniforms. For these uniforms a detailed visual examination was made of each item and the amount of damage was classified as to type, location, and total amount. These evaluations were either completely qualitative or semi-quantitative and must be judged primarily in descriptive terms. Judgments were made of the outer protective garment, the single layer

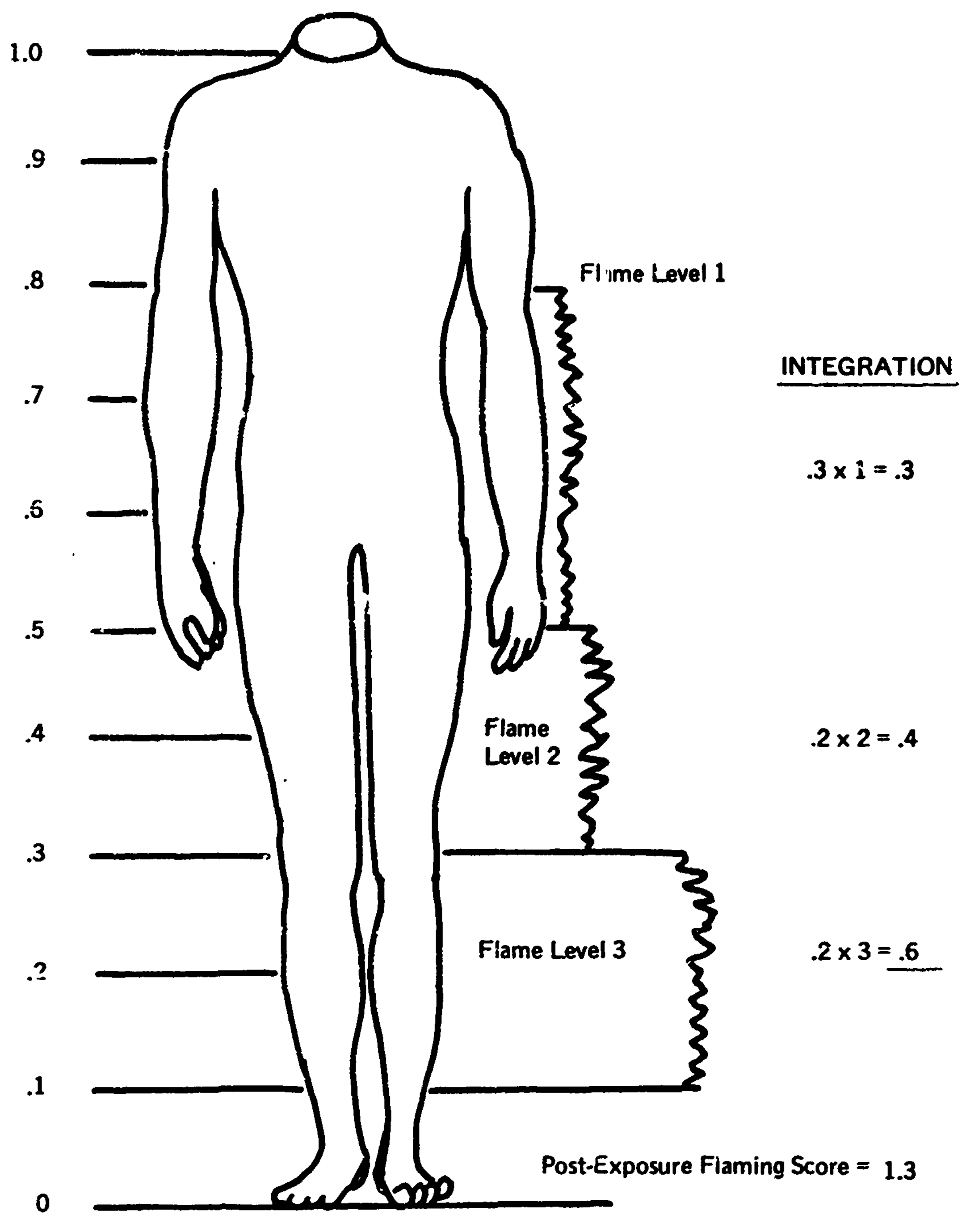


Figure 7 - Method of Computing Post-Exposure Flaming Score

of underwear which was underneath the outer garment in the hot-weather uniforms, and the surface of the manikin itself. Terms used to classify the "type" of damage included: stained, scorched, shrunk, friable, charred, and destroyed. As will be noted subsequently, one or more of these terms could be applied to the various uniform systems. Depending on the fiber and dyestuff type, certain specific systems were particularly characterized by staining (due to dyestuff sublimation) of the underwear layer or by shrinkage. For both the hot-weather and cold-weather uniforms a more realistic assessment of their overall protective ability was obtained by weighting the Temperature-Area Index by the observed Garment Damage for the former and by the Temperature-Area Index and Post-Exposure Flaming Score for the latter.

7. TESTING SEQUENCE AND PROCEDURES

Details on the testing sequence and other aspects of the fire-pit test are contained in the Appendix. In some tests only one manikin was used per trial, in other tests, two or three were used. The possible influence of this variable is discussed in the next section of the report. Other pertinent information that might assist in the interpretation of the data obtained are also presented in the Appendix.

8. SOURCES OF VARIABILITY

Much of the available knowledge on the flame protective qualities of textile materials has come from laboratory tests in which parameters such as ignition delay time and flame spread rate are measured under precise laboratory conditions using specimens of controlled dimensions. Even under these optimum conditions sufficient sampling must be employed to compensate for the inherent variability in flame testing. Large scale flame tests on finished items suffer from the deficiency that the hazard of a given end-item may be as much a function of its design configuration as of its basic fiber composition, fabric construction, and finish. Dimensional scaling has not been particularly successful in flame testing, and, as a result, in recent industrial as well as military efforts to devise flame protective systems, more attention has been directed to the evaluation of the end-item rather than the material components.

In the evaluation of end-items, the amount of variability is a function of both the configuration of the end-item and upon the environmental conditions under which the item is evaluated. It is probable that order-of-magnitude increases in variability result from the configurational problems and from the fact that in large scale testing it is not possible to exercise the same careful control over test conditions. Thus in dealing with end-item testing

it is necessary to increase sample size to insure under controlled experimental conditions that observed differences between compared materials are real. This sampling problem increases the cost of testing and reduces the number of tests that can be accomplished in unit time, but under the present state of technology these are limitations which must be accepted and dealt with.

Variables which must be taken into consideration include the chemical nature of the fiber; fabric weight, cover, density, thickness and finish; and garment characteristics such as drape, pockets, underlayers, closures and general design and construction features. Environmental variables which are most difficult to control are wind velocity and direction, temperature, relative humidity, and convective and radiative influences from the near-by environment of the test facility. Superimposed upon the end-item and environmental influences are the variables in the test method itself. Some of these variables are capable of some control such as the rate of motion of the manikins into the flame, the positions of the manikins to each other and to the flame-pit, and the amount of fuel that is used. However, the capriciousness of the flame and the exact position of the manikin during the short 3 to 10 second interval of testing cannot be controlled with any degree of certainty.

Efforts to obtain a measure of the dispersion of temperature in the flame-pit by the use of thermocouples were not successful, but an average indication of the radiation from a one-position measurement outside of the center-line of the flame-pit by means of a sensitive calorimeter was meaningful. The use of temperature indicating papers which change color over a narrow temperature range provides a useful tool for assessing the maximum "skin" temperature reached by the manikin. However, the area of the manikin to which the noted temperature can be applied can only be judged on the basis of the scorched or browned area surrounding the temperature indicating papers. In addition, the 20° to 30° spread in average indicating temperature among the papers limit their specificity considering their reproducibility within the designated temperature. The difference in behavior of garments made from different fiber types superimposes an element of variability that is difficult to segregate from basic material and design interactions for the particular garment type. For example, the preferred mechanism of failure of some fiber types under the influence of identical flame conditions may be shrinkage, whereas another fiber type fails primarily by the mechanism of charring, becoming friable, and ultimately being destroyed. As part of the initial studies of the cold-weather and hot-weather aviators' uniforms, an analysis was made of the influence of some of the variables that influenced both the maximum temperature reached in various sections of the manikin and in the area coverage for a given temperature as obtained from the charred or browned areas of the manikin surface.

The data reported here to assess variability are based on the same parameter used for demonstrating the differences in protection among the uniforms. The parameter designated as the Temperature-Area Index is computed as follows:

$$\text{Temperature Area Index} = 1.27 \sum a_i b_i$$

a_i = Area of manikin body segment expressed as a percentage (e.g. - Right Buttock = 2.5% of entire body surface area)

b_i = Fractional area of a_i which exceeded a temperature of 221°F. (Fractional area estimated as the scorched or browned area surrounding the temperature indicating paper)*

1.27 = Factor relating total percent of manikin damaged to clothed areas only (Total area less head, neck, feet, and hands).

* - In the absence of a visual indication of the partial area which could be associated with the temperature indicating paper, a b_i of unity was assumed.

To assist in understanding the method of computing the Temperature-Area Index a sample computation for one of the uniform systems is given in Table IV.

TABLE IV

SAMPLE COMPUTATION OF TEMPERATURE-AREA INDEX

Manikin Segment	a_i	b_i	$a_i b_i$
Posterior Trunk - Right	6.5	1.00	6.5
Posterior Trunk - Left	6.5	.31	2.0
Upper Arm - Right	4.0	.75	3.0
Lower Arm - Right	3.0	.17	0.5
Lower Leg - Right	7.0	.50	3.5
Lower Leg - Left	7.0	.29	2.0
$\sum a_i b_i$			17.5
$1.27 \sum a_i b_i$			22.2

For this computation each value of a_ib_i indicates the area attaining a temperature of 221°F for the indicated manikin segment expressed as a percentage of the total manikin area. Thus, for the posterior trunk - right, the entire right posterior trunk was affected, and since the right posterior trunk constitutes 6.5% of the total manikin area, the value of 6.5 appears in the last column.

In the left posterior trunk, just a little over 30% (.31) of this area was affected which comes to 2.0% expressed as a percentage of the entire manikin area. The value of $\sum a_ib_i$ indicates that a total of 17.5% of the manikin area was affected. Since the clothed area of the manikin was only 81% of the total area, the value of 1.27 $\sum a_ib_i$ computes to 22.2%.

a. Variations in Ambient Conditions

To unambivalently evaluate the influence of ambient conditions it would be necessary to assign Temperature-Area Indices for identical systems to each set of measurable variables. For example, a measure of the influence of day-to-day variations in average Temperature-Area Index can be obtained by comparing the daily averages for and variations within stated garment systems. In the cold-weather uniforms this was possible since each ensemble was tested in four daily series of exposures, and in addition at three different levels of intensity. A comparison was made by averaging the Temperature-Area Indices over each garment type and over each intensity level for the four exposure series. As shown in Figure 8, there was a chronological decrease in the value of this average Temperature-Area Index over the four exposure series. An analysis of the meteorological conditions prevailing during the period over which these tests were made showed no systematic change which could account for the observed phenomenon. A statistical analysis of the raw data used in establishing the curve in Figure 8 was tested by Fisher's "t" distribution. The data indicated no statistically significant differences between series, 1, 2, and 3, but a difference at the .05 probability level between series 1 and 4.

In the hot-weather uniform tests, there were also four series conducted over a four-day period. In these tests there were not sufficient items of a similar type to obtain an unequivocal indication of the significance of day-to-day variations. Figure 8 shows the averages of each day's tests - the third series has a relatively high value and the fourth series a relatively low value Temperature-Area Index. A "t" test did not show any significant differences among these averages at the .05 level of probability. In addition, a rough statistical comparison was made between the values of identical items tested in the third series and again in the fourth series. In the third series, three items of two types (designated as Aromatic Polyamide B and C) were evaluated, but in the fourth series only one item of each of these two types was evaluated. Assuming that the single values were triplicated (with identical values) a "t" test was

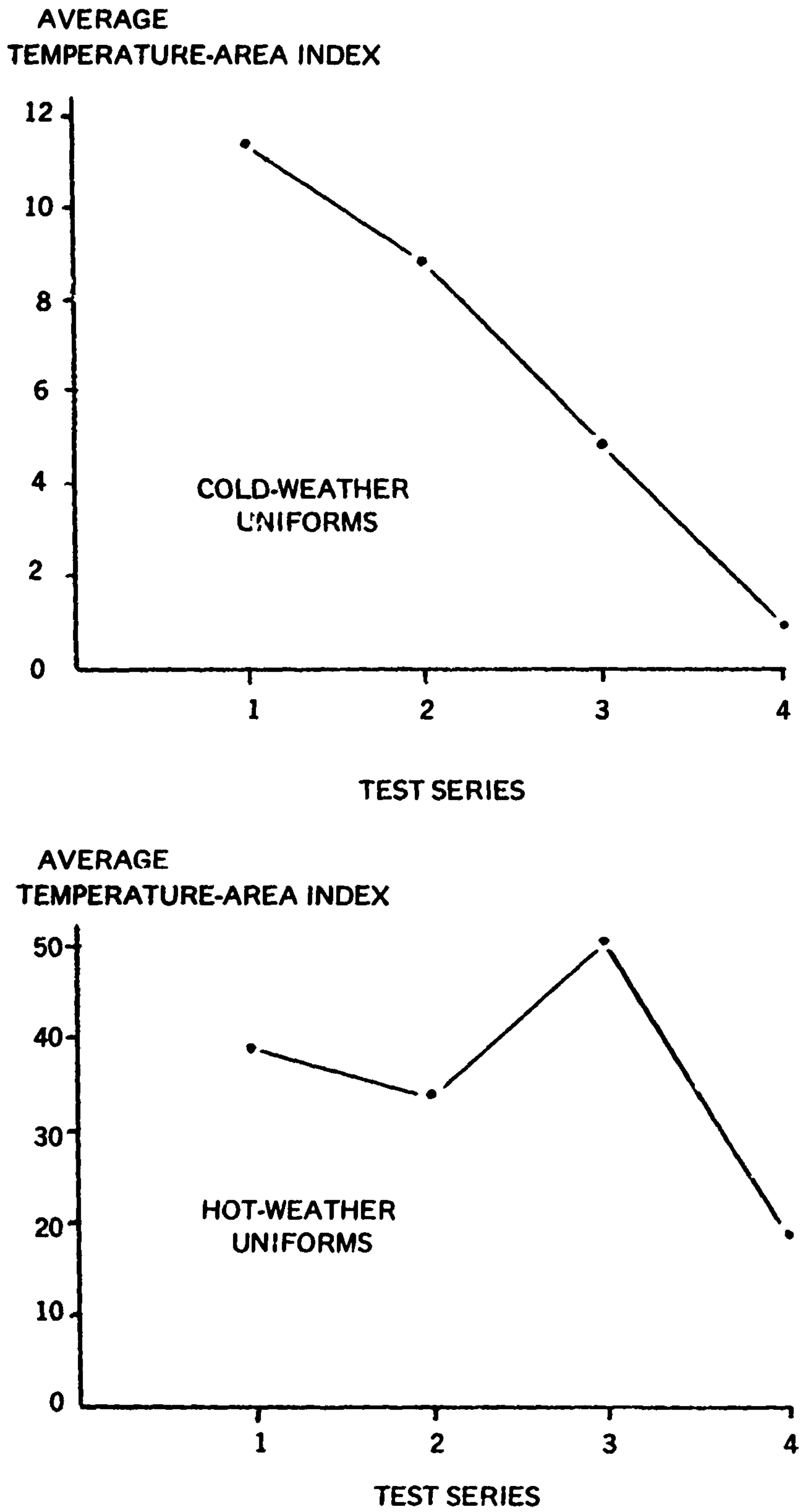


Figure 8 — Variation in Average Temperature-Area Index with Test Series for Cold-Weather and Hot-Weather Uniforms

conducted between the computed means and again no significant differences were obtained at the .05 level of probability. This is an unconventional type of statistical analysis. It very much favors finding significant differences. The fact that none was found corroborates the observation that no significant differences existed among the four series in the hot-weather uniform tests.

b. Variation in Fire Intensity

As indicated above, the thermocouple rake which was used in the test of the cold-weather uniforms did not prove to be successful as a means of estimating the variability in the thermal load imposed by the different fires. In the test of the hot-weather uniforms the radiation-calorimeter which was positioned 18 feet from the end of the fire-pit provided a useful indication of the relative fire intensity in each test series. The mean peak radiance averaged approximately 2 cal/cm^2 in three of the four test series, and just less than 2.6 cal/cm^2 for the other series. In view of the many other sources of variability no adjustment was made for this difference in observed intensity. As mentioned in the section above, "Variations in Ambient Conditions," no statistically significant day-to-day variations in Temperature-Area Index were observed in the hot-weather uniform test series.

c. Variation Due to Position of Manikins

In the cold-weather uniform test series, 2 or 3 manikins were run through the fire as a group. It is probable that this introduced an element of variation in the test results since the manikin in the central position of each run could be partially protected by the manikins in the first and last positions. A plot (Figure 9) of average Temperature-Area Indices for all of the manikins in each position reveals a lower average level for the central position. The difference between the first and central position was significant at the .05 probability level, but the difference between the central position and the last was not. However, by pooling the values for the first and last positions, a significant difference was found between these two positions and the central position.

d. Variation in Manikin Area Affected by Fire

In view of the characteristic anatomy of the manikin and the associated clothing, it is likely that some areas would be more vulnerable to the flame than others. Specifically, it is felt that the extremities (arms and legs) would have higher Temperature-Area Indices because of their greater surface area to volume ratio and their chimney-like configuration which would promote flame travel. This vulnerability was borne out in the

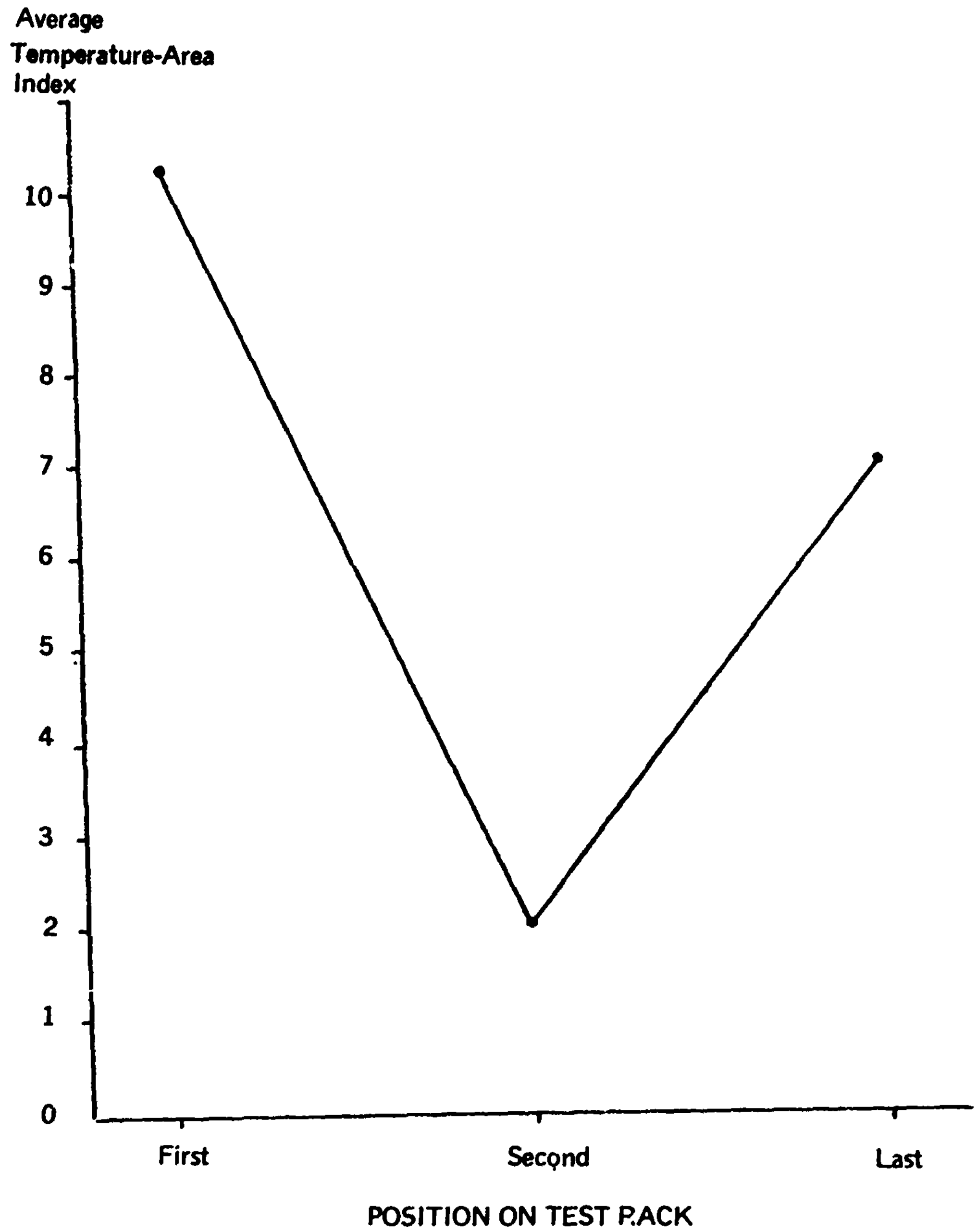


Figure 9 - Average Temperature-Area Index as a Function of Position on the Test Rack
(Cold-Weather Uniform Tests)

tests of the hot-weather uniforms. For example, of the total area of the arms and of the legs, approximately 50% of the former and 40% of the latter reached the temperature threshold of the Temperature-Area Index. In the case of the trunk and the buttock areas, approximately 31% of the former and only 23% of the latter were involved. Further, the posterior (back) positions of the trunk, thighs, and legs sustained higher Temperature-Area Indices than the anterior (front) positions of the manikin. These variations suggest possible areas of the uniforms to which special attention should be paid in terms of providing increased protection. In the posterior versus anterior differences, the presence of pockets in the front of the trunk, arms and legs could account for part of the differences observed.

9. RESULTS

The results of the tests are expressed in terms of three parameters:

1. Temperature-Area Index
2. Post-Exposure Flaming Score (cold-weather uniforms only)
3. Garment Damage (hot-weather uniforms only)

a. Temperature Area Index

The overall results of the Temperature-Area Index evaluations are summarized in Figure 10, in which Temperature-Area Index is plotted against exposure time in the fire-pit. Two ordinates are given. The left-hand ordinate is for the hot-weather uniforms which sustained higher Temperature-Area Indices during testing and the right-hand ordinate is for the cold-weather uniforms which sustained lower Indices during testing. As stated previously, each of the cold-weather uniforms was tested at three exposure times (6, 8, and 10 seconds), which are indicated by the appropriate points in Figure 10. The hot-weather uniforms were tested at one exposure period only (3 seconds), and the values obtained are indicated by short lines on Figure 10.

A general view of Figure 10 makes certain conclusions immediately obvious. First, the overall performance of the cold-weather uniforms is much superior to that of the hot-weather uniforms. At all exposure times (6, 8, 10 seconds) the Temperature-Area Indices for the cold-weather uniforms ranged from a minimum of zero to a maximum of 23. On the other hand, for an exposure time of just 3 seconds, the Indices for the hot-weather uniforms ranged from a minimum of approximately 12 to a maximum of over 55. This marked superiority of the cold-weather uniforms is obviously a function of their greater mass and/or thickness. This point will be discussed further below. In common with many other systems required for protection against weapon or accident hazards, the interposition

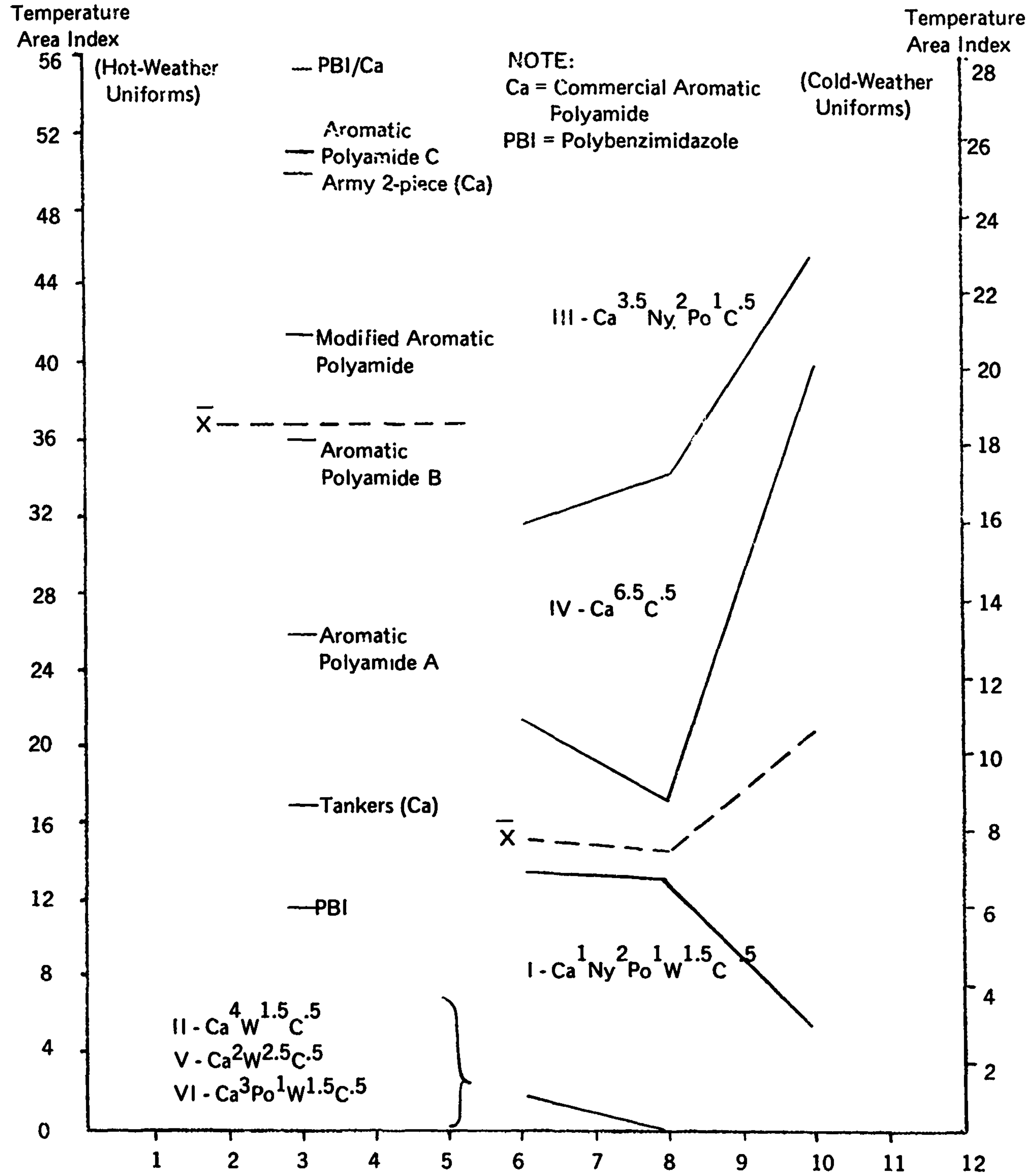


FIGURE 10 - Temperature-Area Index of Aviators' Uniforms as a Function of Exposure Time (Seconds)

of a large mass between the individual and the hazard is one of the simplest means of providing protection. The second general conclusion which may be reached in examining Figure 10 pertains to the spread in values among the various uniform systems tested. The fact that for both uniform systems many of the Temperature-Area Indices observed fell at much lower values than others indicates that mechanisms are available whereby the type of damage characterized by the Temperature-Area Index is capable of modification and probable reduction. However, the influence of the sources of variability discussed previously should not be discounted in assessing these differences.

b. <u>Temperature-Area Index Evaluation of Cold-Weather Uniforms</u>

Because of the complexity of the cold-weather uniform system, it is difficult to exactly segregate the influence of the fiber, fabric, and system variables involved. However, certain generalizations may be reached. To facilitate comparisons of the cold-weather uniforms, a coding system is used in Figure 10 which enables one to roughly identify the fiber types and the number of fabric layers of each fiber type constituting the coverall system. Thus, Ca refers to commercial aromatic polyamide, Ny to nylon, Po - polyester, W - wool, and C - cotton. The power to which each symbol is raised indicates the number of fabric layers composed of that type of fiber in the uniform. Thus, for Ensemble No. III, $Ca^{3.5}\ Ny^{2}\ Po^{1}\ C^{.5}$ denotes an ensemble consisting of 3.5 layers of commercial aromatic polyamide; 2 layers of nylon; 1 layer of polyester, and .5 layers of cotton. The .5 is used because one layer was a blend of commercial aromatic polyamide with cotton. As a group, the performance of the cold-weather uniforms in terms of Temperature-Area Index was satisfactory. Of the six ensembles, three (II, V, and VI) showed either zero or close to zero Temperature-Area Index at all three exposure times. One ensemble (I) showed intermediate performance, and two ensembles (III and IV) yielded relatively high Temperature-Area Indices for the cold-weather uniforms. At first glance it might be assumed that the higher Temperature-Area Indices of these latter uniforms might be associated with the greater number of layers of commercial aromatic polyamide fabric in their systems (3.5 layers for ensemble No. III and 6.5 layers for ensemble no. IV). However, these two systems were the two thinnest and among the three lightest of all of the uniforms tested. A plot of Temperature-Area Index against ensemble weight and against ensemble thickness is shown in Figure 11. It is likely that significant improvements with respect to Temperature-Area Index in the case of these lighter weight commercial aromatic polyamide uniforms could be made by interposing more mass and/or thickness by the use of a thermally stable liner in the system. Concentration of the aromatic polyamide in the outer layers of the ensemble can be expected to give the highest degree of protection provided the mass is equivalent.

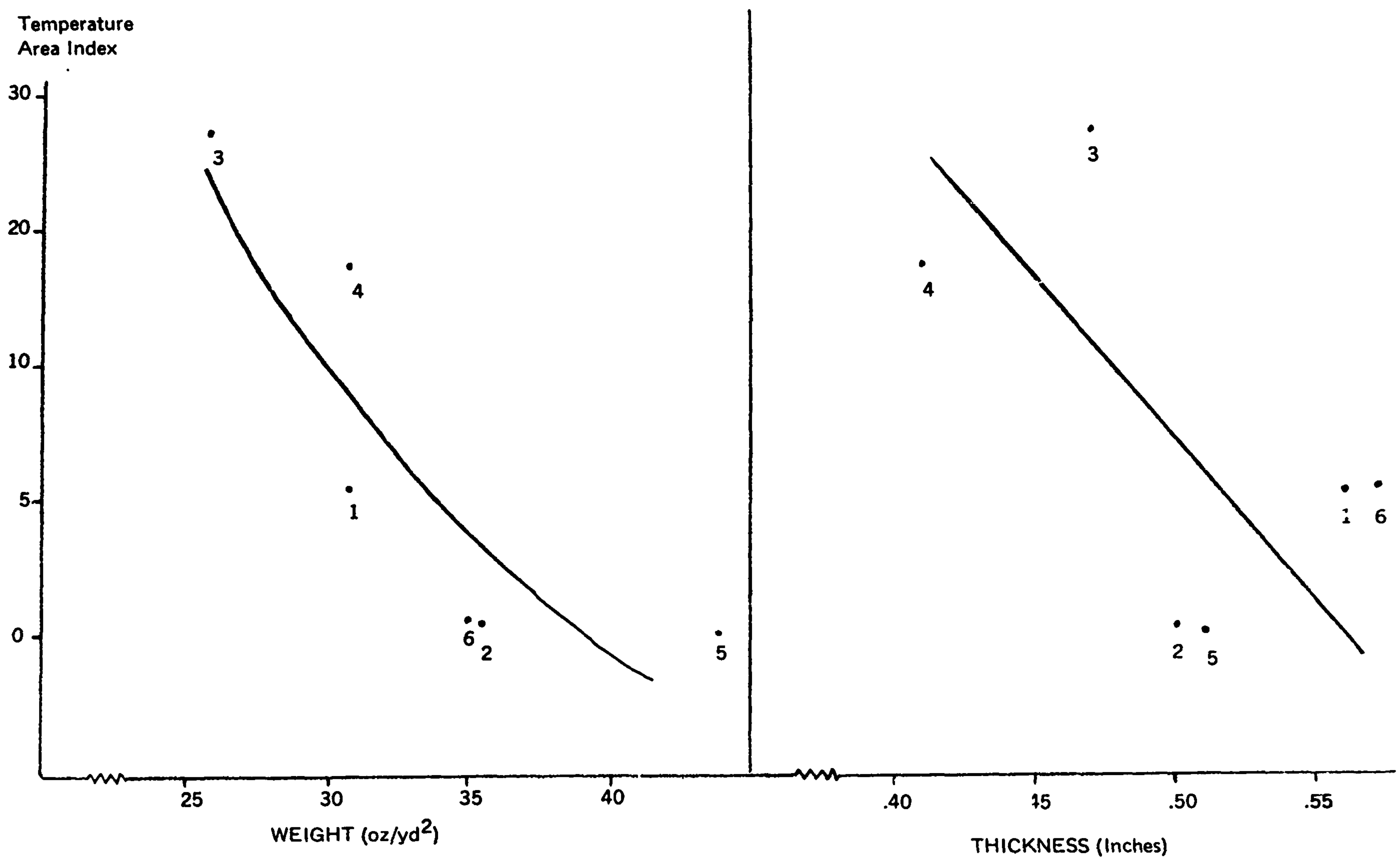


Figure 11 - Relationship of Temperature-Area Index to Weight and Thickness of Cold-Weather Ensembles

c. Post-Exposure Flaming of Cold-Weather Uniforms

As mentioned previously, an analysis was made of the extent of flaming of the cold-weather uniforms in the 5 second interval after they left the fire and before the flaming was extinguished. The extent of flaming was integrated over the manikin length for minor (score 1); intermediate (score 2); and severe (score 3) flaming, as judged from motion picture films. The scores obtained for each ensemble are listed in Table V. The higher the score the greater the amount of post-exposure flaming.

TABLE V

POST EXPOSURE FLAMING SCORES OF COLD-WEATHER UNIFORMS

Uniform No. / Exposure Time Secs.	6	8	10	$\bar{X}$ *
I - $Ca^{1} Ny^{2} Po^{1} W^{1.5} C^{.5}$	2.1	3.1	4.7	3.6
II - $Ca^{4} W^{1.5} C^{.5}$	0.6	1.2	0.4	0.9
III - $Ca^{3.5} Ny^{2} Po^{1} C^{.5}$	3.2	4.1	1.9	4.7
IV - $Ca^{6.5} C^{.5}$	0.6	.6	0.1	0.4
V - $Ca^{2} W^{2.5} C^{.5}$	0.8	.2	0.1	0.7
VI - $Ca^{3} Po^{1} W^{1.5} C^{.5}$	1.4	.8	0.6	1.1

* X - Grand average based on summing individual averages for minor (score 1), intermediate (score 2), and severe (score 3) flaming over 6, 8, and 10 second intervals.

It is apparent from Table V that the highest flame scores were noted in ensembles I and III. These were the only two ensembles in which nylon covered polyester batting was utilized as the insulating layer. The rankings of Temperature-Area Index and Flaming Scores are shown in Table VI.

TABLE VI

COMPARISON OF RANKINGS OF COLD-WEATHER UNIFORMS

Temperature-Area Index Rank	Uniform System	Flaming Score Rank
1	V - $Ca^{2} W^{2.5} C^{.5}$	2
2	II - $Ca^{4} W^{1.5} C^{.5}$	3
3	VI - $Ca^{3} Po^{1} W^{1.5} C^{.5}$	4
4	I - $Ca^{1} Ny^{2} Po^{1} W^{1.5} C^{.5}$	5
5	IV - $Ca^{6.5} C^{.5}$	1
6	III - $Ca^{3.5} Ny^{2} Po^{1} C^{.5}$	6

* Rank of averages for 6, 8, and 10 second exposures and for all four test series.

The agreement among the ranks is quite good except in uniform system No. IV which had the lowest Flaming Score but a high Temperature-Area Index. This is an expected result since uniform No. IV was the thinnest of all of the uniforms particularly over the lower torso and thus would be expected to have a high Temperature-Area Index. But since it had the highest concentration of commercial aromatic polyamide, it would have good flame resistance. Computation of a Rank-Difference Coefficient of Correlation for the data in Table VI yielded a Rho value of 0.43. With the exclusion of uniform No. 4 this Rho value would be much higher (0.80).

d. Temperature-Area Index Evaluation of Hot-Weather Uniforms

The short horizontal lines on the left side of Figure 10 denote the level of Temperature-Area Index (left ordinate scale) sustained by the hot-weather uniform systems. With the exception of the Army 2-piece and Tankers designations, all of the other uniforms are

designated by the fiber composition of the outer layer. These latter uniforms were of the Air Force coverall type illustrated in Figure 6. As was the case with the cold-weather uniforms, the level of performance of these uniforms must be judged not only in terms of the fiber composition, but also in terms of the garment configuration. In the hot-weather uniforms there was not a sufficient number of samples of each type tested to permit drawing any but the most cursory conclusions from the Temperature-Area Index evaluations. For example, at the .05 probability level, the PBI coveralls were significantly superior, from the standpoint of Temperature-Area Index, to the PBI/Ca* and aromatic polyamide C coveralls, but not to any of the other uniforms. The inability to find clear significant differences in Temperature-Area Index among the hot-weather uniform systems, despite the separation of average values, demonstrates the need for increasing the number of uniforms of a given type tested in future test series. However, the "after-appearance" evaluation of the hot-weather garments, as discussed below did add an element of support to the observed average values of the Temperature-Area Index.

e. After-Appearance Evaluation of Hot-Weather Uniforms

The analysis of the appearance of the garments was done on a layer basis by considering the outer uniform or coverall, the underwear and the manikin itself. The analysis is in purely qualitative terms but a ranking was devised which permits comparisons. A precis of each qualitative assessment of the uniforms is given below in order from the least to the most damaged. The Army Tankers Coverall because of its double layer construction protected the underwear and the manikin and is ranked third. If ranking were based on the performance of the outer layer only, it would be ranked sixth.

PBI

Uniform: Intact, heavy shrinkage,heavy scorching - legs and buttocks
Underwear: Little damage
Manikin: No damage

Aromatic Polyamide A

Uniform: Intact, random char and scorching
Underwear: Spotty char and light stain
Manikin: Stained in areas not covered by underwear

Army Tankers (Ca)

Uniform: Heavy char below waist, heavy contraction with rupturing (back and chest), minimal char on 2nd commercial aromatic polyamide layer (back).
Underwear: No damage
Manikin: No damage

*Ca= commercial aromatic polyamide

PBI/Commercial Aromatic Polyamide

Uniform:	Intact, heavy shrinkage, scorched particularly over lower portion
Underwear:	Damage - thighs and buttocks
Manikin:	Charring - thighs and buttocks

Aromatic Polyamide B

Uniform:	Charred, friable, or shrunk
Underwear:	Heavy green stain over torso, minimal charring at crotch and buttocks
Manikin:	Range of stains - light to heavy

Aromatic Polyamide C

Uniform:	Intact with varying degrees of damage, heat shrunk, stiff, some charring and friable
Underwear:	Heavy staining, scorched and charred areas - thigh and mid-section
Manikin:	Heavy staining

Army 2-piece (Ca)

Uniform:	Essentially destroyed
Underwear:	Stained, segments of thighs charred
Manikin:	Lightly charred above thighs

Modified Aromatic Polyamide

Uniform:	Heavily damaged, scorched, friable, destroyed, some with thermal shrinkage, scorching and charring
Underwear:	Heavy char and scorch, some light and heavy stains
Manikin:	Moderately stained where uniform destroyed

In general, the observations of the burned garments agreed with the assessments made by the Temperature-Area Index. The relative rankings by each system of evaluation are shown in Table VII.

TABLE VII

COMPARISON OF RANKINGS OF HOT-WEATHER UNIFORMS

Temperature-Area Index Rank	Uniform System	Garment Damage Rank
1	PBI	1
3	Aromatic Polyamide A	2
2	Army Tankers (Ca)*	3
8	PBI/Ca*	4
4	Aromatic Polyamide B	5
6	Aromatic Polyamide C	6
7	Army 2-Piece (Ca)*	7
5	Modified Aromatic Polyamide	8

*Ca = Commercial Aromatic Polyamide

Computation of Rank-Difference Coefficient of Correlation for the set of values in Table VII yielded a Rho value of 0.67 indicating some association between the two sets of ranks. As is the case with all of the data in this report, this association can only be considered valid for the uniform systems, specific materials, and conditions of this test.

In addition, there appears to be an element of association between the rankings of garment damage and the rankings obtained in the laboratory flame-contact test (Federal Test Method Standard No. 191 - Method 5905). Using the data for the warp direction of the various fiber types comprising the outer layer of the experimental hot-weather items as listed in line 9 of Table A2 in the Appendix (under "After Flame Sec."), and converting these values to ranks, a coefficient of correlation analysis yielded a Rho value of 0.69. In making this correlation the Army Tankers Uniform was excluded because of its double layer construction. This correlation indicates that the laboratory flame contact test may be a useful procedure for screening candidate heat and melt resistant fiber types prior to their consideration for use in protective uniforms.

10. CONCLUSIONS

1. The Fire-Pit Test appears to be a suitable device for exposing uniforms to large-scale fuel fires and making assessments of relative performance levels of systems involving different designs, fabric characteristics, and fiber types.

2. As is characteristic of most full-scale testing systems involving clothing, it is necessary to use a sufficiently large sample size to compensate for the inherent variability in the testing system. This is particularly true in the case of fire tests in which positive control cannot be exercised over the capricious nature of flaming.

3. Within the limitations imposed by various sources of variability, it is possible to make judgments as to the relative effectiveness of certain uniform systems.

4. There is a significant advantage in using heavier and thicker uniform systems when permitted by environmental conditions.

5. There is an advantage in using high-temperature resistant, non-melting fiber types.

6. While only three PBI uniforms were available to test, based on this limited sample size, it appears that the polybenzimidazole fiber performed better than the other heat-resistant fibers in terms of average Temperature-Area Index and After-Appearance Evaluation. Noteworthy is the fact that the polybenzimidazole coverall retained its structural integrity better than coveralls made from the other fiber types.

7. There appears to be a disadvantage in using polyester battings quilted between layers of nylon in the cold-weather uniform systems because of their after-flaming properties.

8. The Temperature-Area Index appears to be a useful parameter for characterizing temperature rise in terms of area coverage at the surface of the manikin.

9. Post-Exposure Flaming and/or visual assessment of garment damage - useful and necessary adjuncts to the evaluation of Temperature-Area Index.

10. Even with the limited number of samples evaluated in this test, the fact that there was a degree of association between temperature-area indices and post-exposure flaming scores for the cold-weather uniforms - and between temperature-area indices and assessment of garment damage for the hot-weather uniforms, indicates a basis of validity in using the fire-pit facility as a test evaluation procedure.

11. Times of after-flame as measured by the laboratory flame-contact test are useful for characterizing materials prior to subjecting them to the fire-pit test.

12. In all future tests, it is essential that the number of garment and fiber variables be kept to an absolute minimum and that sample size be increased to facilitate the derivation of statistically significant differences. Considering cost factors, it is judged that 10 identical uniforms would probably constitute a minimum useful sample size - (See Appendix B).

11. REFERENCES

1. Turnbow, J. W., D. F. Carroll, J. L. Haley, W. H. Reed, S. H. Robertson, and L. W. T. Weinberg, "Crash Survival Design Guide", Report 67-22, U. S. Army Aviation Materiel Laboratories (July 1967).

2. Waldron, E. T. and W. M. Koza, "Study of the Effectiveness of Textile Materials Against Intense Thermal Radiation: Part 1 - Experimental Techniques", Report No. 176, U. S. Army Natick Laboratories (1958).

3. Chen, N. Y. and W. P. Jensen, "Skin Simulants with Depth Magnification", Report No. 5, Fuels Research Laboratory, Massachusetts Institute of Technology, Cambridge, Mass. (1957).

4. Loconti, J. D., S. L. Knesbach, and E. O. Weil, "Temperature Indicator Papers", Report No. GC-30, Pioneering Research Laboratories, U. S. Army Natick Laboratories, (1951).

APPENDIX A

TABLES

APPENDIX B

TABLE A1

COMPONENTS OF COLD-WEATHER AVIATORS UNIFORMS

ITEM	ENSEMBLE TYPE	FABRIC	Fabric Weight (Oz/Yd^2)	Fabric Thickness (In.at .05psi)	REMARKS
Underwear	I, II, V, and VI	50/50 wool/cotton	8.9	.068	Type I, Class I, MIL-D-43261
	III and IV	50/50 Cotton/Ca*	5.8	.051	
Shirt	I, II, V, and VI	85/15 Wool/Nylon	11.1	.100	MIL-S-10858 Stp.
	III and IV	100 Ca	4.4	.035	Two Layers of Fabric Used - Inner Garment
Trousers	I, II, V, and VI	85/15 Wool/Nylon	11.1	.100	MIL-S-10858 Stp
	III and IV	100 Ca	4.4	.035	Two Layers of Fabric Used - Inner Garment
	I, II, III, V, and VI	100 Ca	4.4	.035	Single Layer of Fabric Used as Outer Garment
Coat	I, II, III, V, and VI	100 Ca	4.4	.035	Single Layer of Fabric Used as Outer Garment
Jacket	IV	Ca	—	—	Single Layer of Ca* Fabric with Ca Batting
Liner	I and III	Polyester/Nylon	6.2	.370	Type III, Class I, Style A of MIL-B-41826 - Polyester Batting Quilted between Rip-Stop Nylon
	II and III	Ca	11.0	.310	Ca Batting Quilted Between Two Layers of Ca Fabric
	V	Wool	19.2	.320	Wool Frieze (Napped) with a Ca Outer Layer
	VI	Fire Resistant Treated Polyester and Ca	10.4	.380	Fire Resistant Treated Polyester Batting Quilted Between 2 Layers of Ca Fabric

* Ca = Commerical Aromatic Polyamide

TABLE A2

PROPERTIES OF FABRICS USED IN HOT-WEATHER AVIATORS UNIFORMS

	Commercial Aromatic Polyamide	A Aromatic Polyamide	B Aromatic Polyamide	C Aromatic Polyamide	PBI/Ca*	PBI	Modified Aromatic Polyamide
Fabric Weight oz/yd^2	4.4	4.7	4.3	4.6	4.8	4.8	4.5
Weave	2/2 LH Twill	2/2 LH Twill	2/2 LH Twill	2/2 LH Twill	2/1 LH Twill	2/1 RH Twill	Plain
Thickness In. .05 PSI	0.015	0.016	0.015	0.014	0.015	0.016	0.016
Texture W x F	102 x 74	122 x 84	124 x 90	136 x 102	68 x 62	69 x 62	50 x 43
Breaking Strength Lbs. W x F	141 x 139	232 x 192	84 x 55	102 x 75	110 x 100	101 x 95	152 x 133
Tear Strength Lbs. W x F	19 x 22	9 x 8	9 x 6	6 x 5	16 x 18	14 x 10	14 x 12
Air Permeability Ft^3/Min/Ft^2	128	75	115	71	124	98	204
Moisture Regain %	4.5	4.4	—	--	8.5	13	4.5
Flame Resistance *** After-Flame(sec)	6 **	0 x 0	0 x 0	17 x 4	4	0	4

* Commercial Aromatic Polyamide
** Warp Tests Only
*** Method 5905 of CCC-T-191

TABLE A3

FIBER PROPERTIES OF COMMERCIAL AROMATIC POLYAMIDE AND POLYBENZIMIDAZOLE

	Commercial Aromatic Polyamide	Polybenzimidazole
Density (gm/cm^3)	1.38	1.34 - 1.36
Tenacity (gm/den)	5.3	4.1
Elongation Break (%)	22.0	7 - 22
Moisture Regain (%)	5.0	13.0
Chemical Composition	Aromatic Polyamide	Polybenzimidazole
Resistance to Chemicals		
Solvents	Good	Fair
Acids	Fair	Good
Alkali	Poor to Good	Good
Dyeability	Yes	Yes

TABLE A4

TEMPERATURE-AREA INDEX COLD WEATHER UNIFORMS

Test Series	1			2			3			4		
Exposure Time (sec)												
No.*	6	8	10	6	8	10	6	8	10	6	8	10
I	27.3	10.2	10.8	0	8.3	0	0	7.5	0	0	0	0
II	3.6	0	0	0	0	0	0	0	0	0	0	0
III	2.5	36.4	39.1	26.7	21.6	17.5	30.2	3.6	30.1	4.1	5.7	5.1
IV	35.6	8.6	24.8	4.3	26.8	45.5	3.1	3.1	8.9	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0
VI	0	0.9	4.4	0	0	0	0	0	0	0	0.2	1.1

* - Ensemble Number

TABLE A5

TEMPERATURE-AREA INDEX HOT-WEATHER UNIFORMS
(Individual Test Results)

SERIES	ENSEMBLE TYPE	TEMPERATURE-AREA INDEX*
1	Army 2-Piece (Ca)**	49.8
	Modified Aromatic Polyamide	26.7
	Modified Aromatic Polyamide	84.6
	Modified Aromatic Polyamide	17.4
	PBI/Ca	36.1
	PBI	22.2
2	Modified Aromatic Polyamide	4.4
	Modified Aromatic Polyamide	75.4
	PBI/Ca	75.0
	PBI	12.2
	Army Tankers (Ca)	18.4
	Aromatic Polyamide A	5.8
	Aromatic Polyamide C	16.3
	Aromatic Polyamide B	26.7
3	Aromatic Polyamide C	28.6
	Aromatic Polyamide A	33.8
	Aromatic Polyamide B	18.3
	Aromatic Polyamide C	79.9
	Aromatic Polyamide A	38.5
	Aromatic Polyamide B	69.3
	Aromatic Polyamide C	86.5
	Aromatic Polyamide B	54.4
4	Aromatic Polyamide C	43.8
	Army-Tankers (Ca)	15.9
	PBI	6.6
	Aromatic Polyamide B	13.1

* - 3 Second Flame Exposure
** - Ca = Commercial Aromatic Polyamide

TABLE A6

BODY AREA DISTRIBUTION
ADULT MALE

AREA	PERCENT
Head	7.0
Neck	2.0
Anterior Trunk	13.0
Posterior Trunk	13.0
Right Buttock	2.5
Left Buttock	2.5
Genitalia	1.0
Right Upper Arm	4.0
Left Upper Arm	4.0
Right Lower Arm	3.0
Left Lower Arm	3.0
Right Hand	2.5
Left Hand	2.5
Right Thigh	9.5
Left Thigh	9.5
Right Leg	7.0
Left Leg	7.0
Right Foot	3.5
Left Foot	3.5
	100.0

TABLE A7

(On following page)

POST-EXPOSURE FLAMING SCORES

COLD-WEATHER AVIATORS UNIFORMS

Computational Method

* - Flaming Level

** - 2.05 = (.4 + 1.0 + .35) /3 + (.6 + 2.0 + 1.8)/3

*** - 3.64 = (.4 + 1.0 + .35 + .35 + .75 + .3 + .47 + .55 + 1.17)/9 + (.6 + 2.0 + 1.8 + 0.6 + 2.0 + 1.04 + 2.0)/7 + (1.44 + 1.8)/2

Exposure Time (Secs)	Series No.	Run No.	$Ca^1Ny^2Po^1W^{1.5}C^{.5}$ Type I			$Ca^4W^{1.5}C^{.5}$ Type II			$Ca^{3.5}Ny^2Po^1C^{.5}$ Type III			$Ca^{6.5}C^{.5}$ Type IV			$Ca^2W^{2.5}C^{.5}$ Type V			$Ca^3Po^1W^{1.5}C^{.5}$ Type VI	
			1*	2*	3*	1	2	3	1	2	3	1	2	3	1	2	3	1	2
6	1	1	.4								2.7					.94			
	1	2				0	0					.3						.5	
	2	1					1.3					.48							2.0
	2	2	1.0	.6					.35	.96	1.95				.30				
	3	1	.35	2.0		.47			.52	.96									
	3	2											.6			.34			1.3
	4	1		1.8					.35		.90				.17	.30			
	4	2				0	0					0	0					0	0
	Average Score		.58	1.47		.16	.43		.41	.96	1.85	.26	.3		.24	.53		.25	1.1
				2.05**			.59			3.22			.56			.77			1.35
8	1	3				.1						.1						.75	
	1	4	.35						.7		3.0				.35				
	2	3	.75	.6							3.0				.35				
	2	4				.5	.78						.6					.2	1.0
	3	3	.3	2.0		.5					6.0								
	3	4										0	0		.15			.1	
	4	3				.7						0						0	0
	4	4	.47	1.04	1.44				.52		1.95				0				
	Average Score		.47	1.21	1.44	.45	.78		.61		3.49	.03	.6		.21			.26	.52
				3.12			1.23			4.10			.63			.21			.78
10	1	5																	
	1	6																	
	2	5	.55		1.8	.47						.36							
	2	6								2.6					.27			.77	
	3	5		2.0		.17				2.0									
	3	6										0			0	0		0	0
	4	5	1.17			.55			.15	.70									
	4	6										0			.27	.6		.17	.6
	Average Score		.86	2.0	1.8	.40			.15	1.77		.12			.18	.30		.31	.30
				4.66			.40			1.92			.12			.48			.61
Grand Average Score			.59	1.43	1.62	.35	.32		.43	1.44	2.79	.14	.3		.21	.44		.28	.83
				3.64***			.87			4.66			.44			.65			1.11

APPENDIX B

ESTIMATE OF SAMPLE-SIZE REQUIREMENTS FOR FUTURE FIRE-PIT TESTING

In order to determine a realistic sample size to use in future fire-pit test programs, the ASTM equation of E-122-58* was used:

$$n = (3\sigma/E)^2$$

where n = sample size

σ = estimate of the standard deviation of the lot

E = maximum allowable difference between the estimate to be made from the sample and the results of testing the entire population (a measure of precision).

3 = a factor corresponding to a probability of 3 parts in 1000 that the difference between the sample estimate and the total population is greater than E.

This equation bases the sample size on the precision with which a sample average approximates the mean of the population from which the sample was drawn.

For the hot-weather series of uniforms made in the Air Force coverall style, the standard deviations of the temperature-area index ranged from 6.5 to 32.2. A plot of sample size (n) versus standard deviation (σ) for E values ranging from 5 to 20 is shown in Figure B1. As expected, for high values of standard deviation and low E values (high precision), the sample size required becomes inordinately high. For an E value of 20, the sample size required ranges up to a maximum of 14 for a standard deviation of 25.

The average standard deviation for temperature-area index of the hot-weather uniforms is 21.7. For an E value of 20, this would require a sample size of about 10. For those uniforms having a lower standard deviation than 21.7, the testing precision obtainable would be greater, whereas for those having a higher standard deviation than 21.7 the precision would be less. The sample size of 10 appears to be a reasonable compromise considering the present state of development of the fire-pit test. As additional testing controls are developed, it is quite probable that lower values of E will be obtainable and the test will have a correspondingly high precision.

---

* "Choice of Sample Size to Estimate the Average Quality of a Lot or Process," (E122-58) ASTM Standard on General Test Methods (1970).

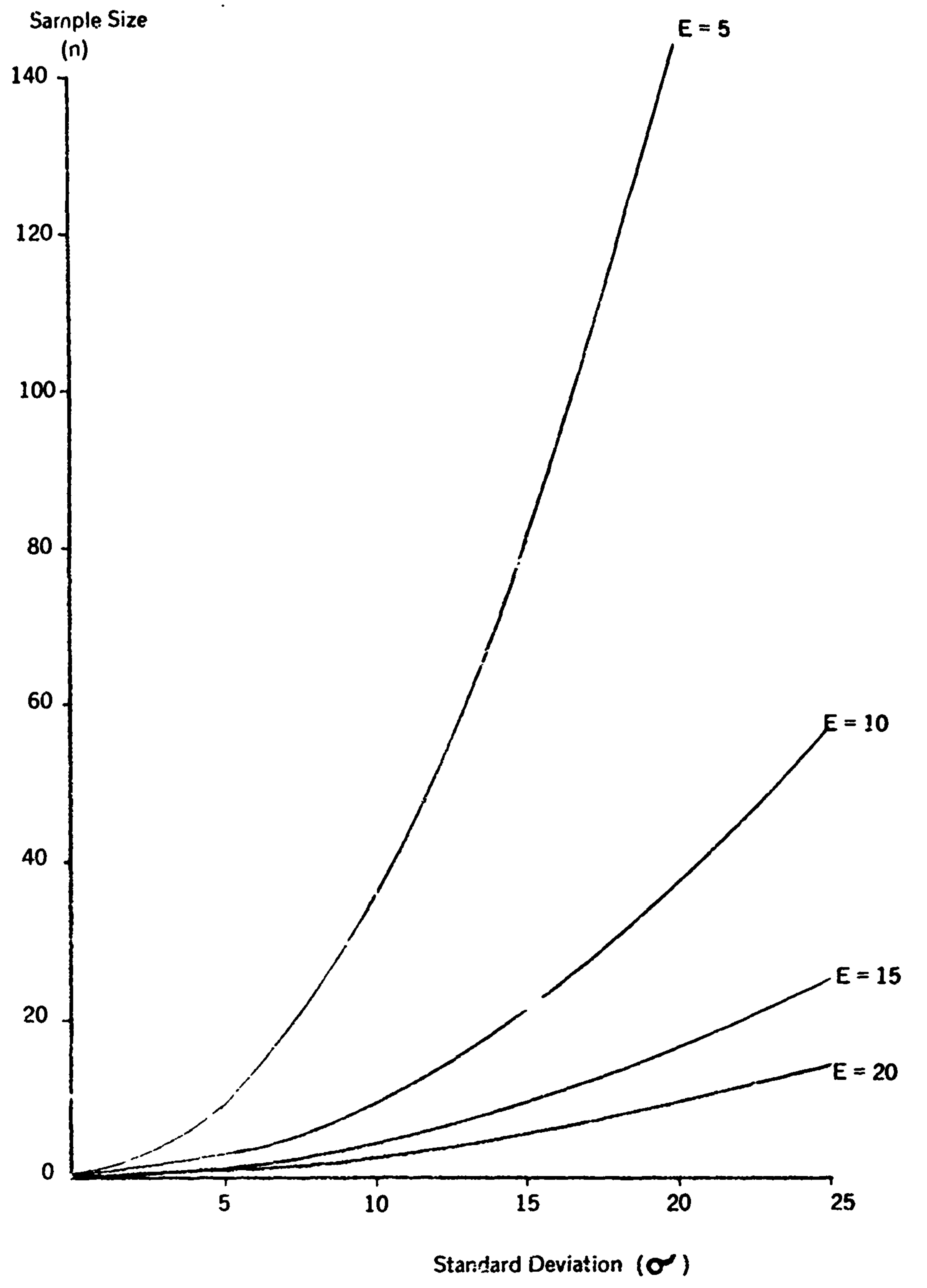


FIGURE B1 - Sample Size in Terms of Standard Deviation (σ') and Maximum Tolerable Difference Between Sample and Population (E) for Temperature-Area Index of Hot-Weather Uniforms